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Shot-time Photography at the National Ignition Facility

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ABSTRACT

The Nation Ignition Facility (NIF) conducts a variety of experiments to study matter at the extremes, including studies of material properties, hydrodynamics, and the interaction of intense radiation fields with matter. The NIF supports the users by operating twenty-four hours a day, with a laser shot rate that averages one per day.

We have developed a shot time camera that has the capability to provide an image of each shot for the users. While initially more of a promotional tool, there is emerging interest from the scientific staff in support of their experiments at the NIF. The shot time camera is a time integrated, shot-triggered, digital camera that images visible light generated at shot time in the NIF target chamber. It is selectable by the user and operates automatically with the NIF shot cycle. We will discuss the system design, recent results, and plans for the future.

Keywords: photography, digital camera, trigger, NIF target chamber

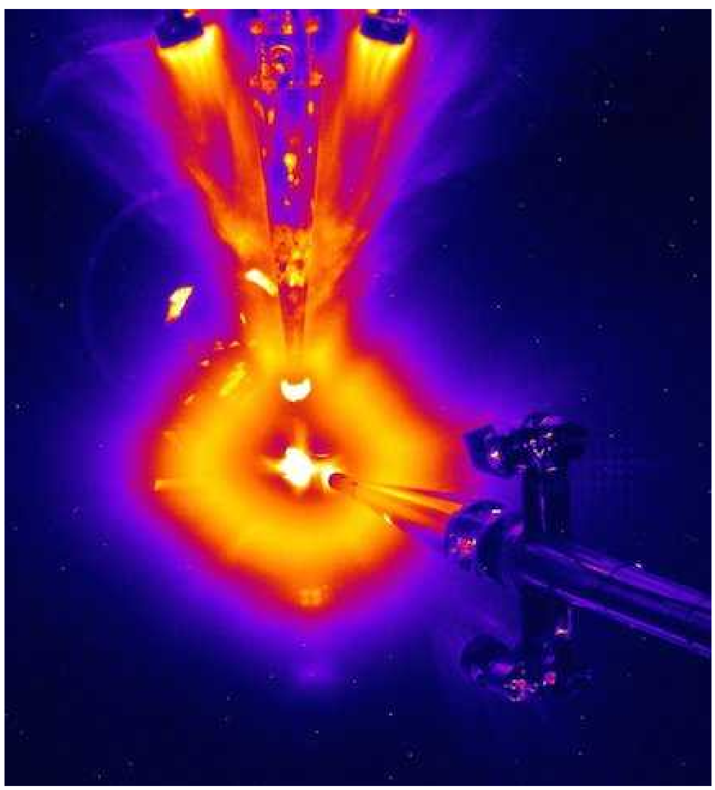

Figure 1. False color image of NIF shot N141001H_CVal_1DSConA_2Shk_S02b, October 2, 2014

1. INTRODUCTION AND BACKGROUND

We have developed a shot time camera that has the capability to provide an image of each NIF shot. The shot time camera is a time integrated, shot-triggered, digital camera that images visible light generated at shot time in the NIF target chamber. For the NIF, a typical laser pulse is 3ns duration, and it is this 3 nanosecond 'flash' that provides the exposure for our photography. Laser pulses are typically on the order of 390TW/1.78MJ at 3 omega (351nm). The shot generates a very intense plasma discharge in the visible resulting from the interaction of laser light and x-rays with the target and the surfaces of nearby diagnostic equipment. It is this plasma discharge that is imaged, along with any unconverted laser light in the visible spectrum. The plasma, for the most part, appears as an intense arc between conducting surfaces.

Compounding the problem is the dynamic range of the camera, which for our setup is about 10-bit (ten stops, or 2^{10}), which is typical of modern digital SLRs. Proper exposure so as not to saturate the image of plasma in the region of the target would require neutral density filters of ND8 or larger and we would not be able to cover any details of any other elements inside the target chamber. So what we do is intentionally over expose a good portion of the overall image, which allows us to retain detail in the dark areas in post processing. Our images have a depth of 12-bits. Film does offer some improvement in dynamic range, over digital; this will be the subject of future work.

We do employ neutral density filters, typically in the range ND5 to ND8. Some of these filters are neutral apodizers (dark in the center brighter toward the perimeter of the filter) that vary three orders of magnitude across the diameter of the filter.

Another issue is radiation damage. Irradiation by 14 MeV neutrons degrades the signal to noise ratio, and causes permanent damage to the imager chip and the associated electronics. High yield shots can generate 1E16 neutrons or more, resulting in fluences on the order of 1E10 n/cm^2 at the camera, which is about threshold for damage. For this reason the camera is rarely run on high yield shots, but use of a film camera would eliminate this problem.

Since diagnostic real estate is in high demand on the NIF target chamber, the shot time diagnostic shares a diagnostic port. The camera views the target through a vacuum window that is protected by another window (non vacuum) that serves as a debris shield. When not in use, the vacuum window/debris shield assembly is isolated from the target chamber by a vacuum gate valve.

2. EXPERIMENTAL SETUP

The shot time camera is located at Port D 77,54 (Θ,Φ), on the NIF target chamber. Figure 8 shows the port layout. Working back from the target chamber, we have: gate valve, debris shield, vacuum window, and camera. The gate valve allows change out of the vacuum window and / or debris shield assembly without compromising the target chamber vacuum. When the camera is not in use, the gate valve remains closed. Over the course of ten shot photos, no damage was observed on the debris shield.

The photo in Figure 9 shows the camera enclosure as deployed at Port D. The enclosure is light tight. It contains kinematic mounts that accept the camera. Connections to the enclosure include only the shutter shot trigger (a 4 volt pulse of 200 nanoseconds duration that precedes the laser shot by 750 microseconds) and power over Ethernet.

The camera is a Basler A641f monochrome imager. Is has an advertised dynamic range of 9.9 stops with a bit depth of 12-bits. The chip is 1624x1236 (2MPix) with 4.4 micron x 4.4 micron pixels.

The camera is 5 meters distant from target chamber center. It is equipped with a 35 mm lens that provides a one-meter field of view. Only visible light is imaged. The transmission curve for the lens is provided in Figure 10. We use considerable neutral density filtering, typically ND5 to ND8, including an apodizer filter shown in Figure 11.

Typical shot photography parameters are: 3ns exposure time, ISO 200, f/5.6, ND5.5. N_DoD_Xray_PDI_S02. Note that this is approximately 20 stops, or 2^{20}, brighter that what is needed for solar photography (Refer to Figure 7)!

3. RESULTS

A collection of shot time photos follows.

Acronyms:

XTRRA – X-ray Transport Radiation Response Analysis

DIM - Diagnostic Insertion Module

GXD - Gated X-ray Diagnostic

VISAR - Velocity Interferometry System for Any Reflector

HGXD - High Yield Gated X-ray Diagnostic

TARPOS – Target Positioner

DISC – DIM Imaging Streak Camera

Wedge Range Filters – proton energy spectrometers

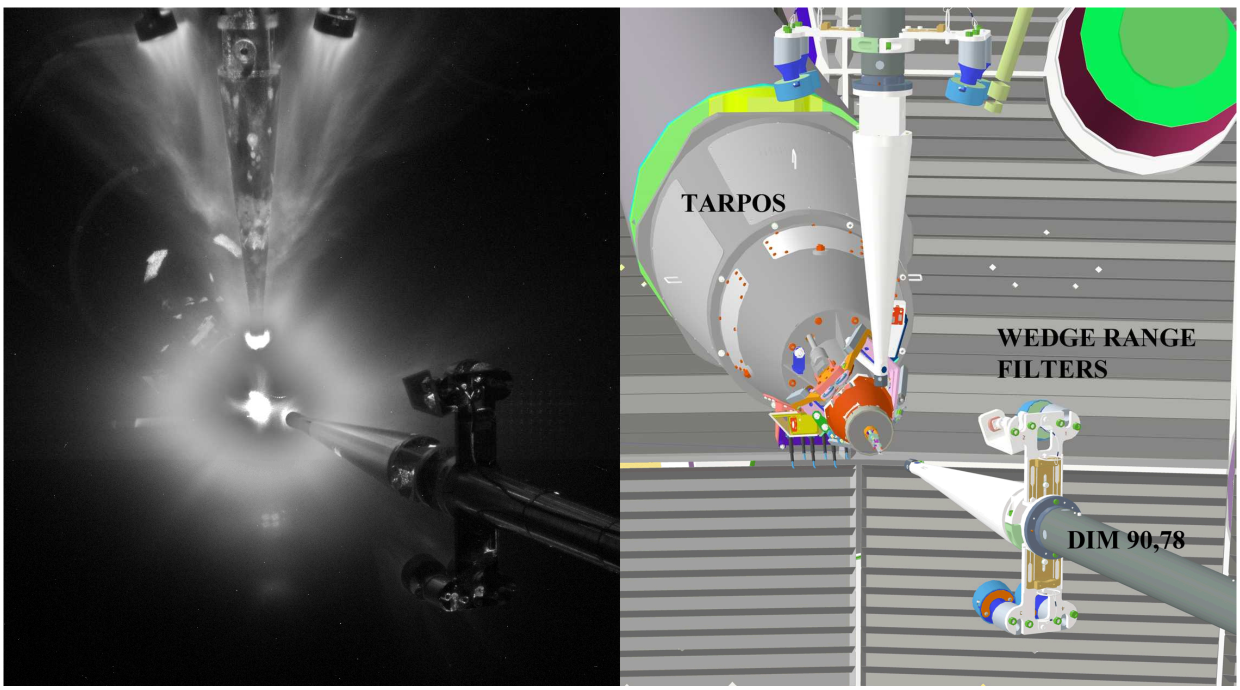

Figure 2. NIF shot N141001 H_CVal_1DSConA_2Shk_S02b, October 2, 2014

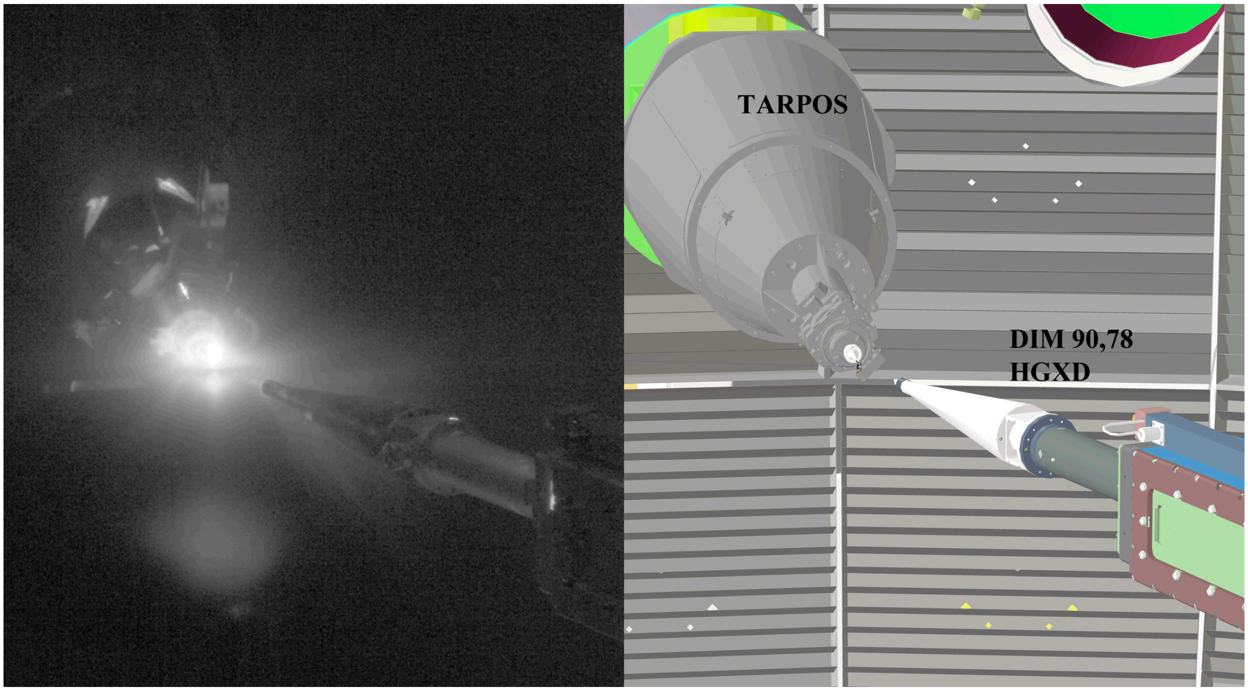

Figure 3. NIF shot N151012 H_Hyd_Shktub_Shear, January 12, 2015

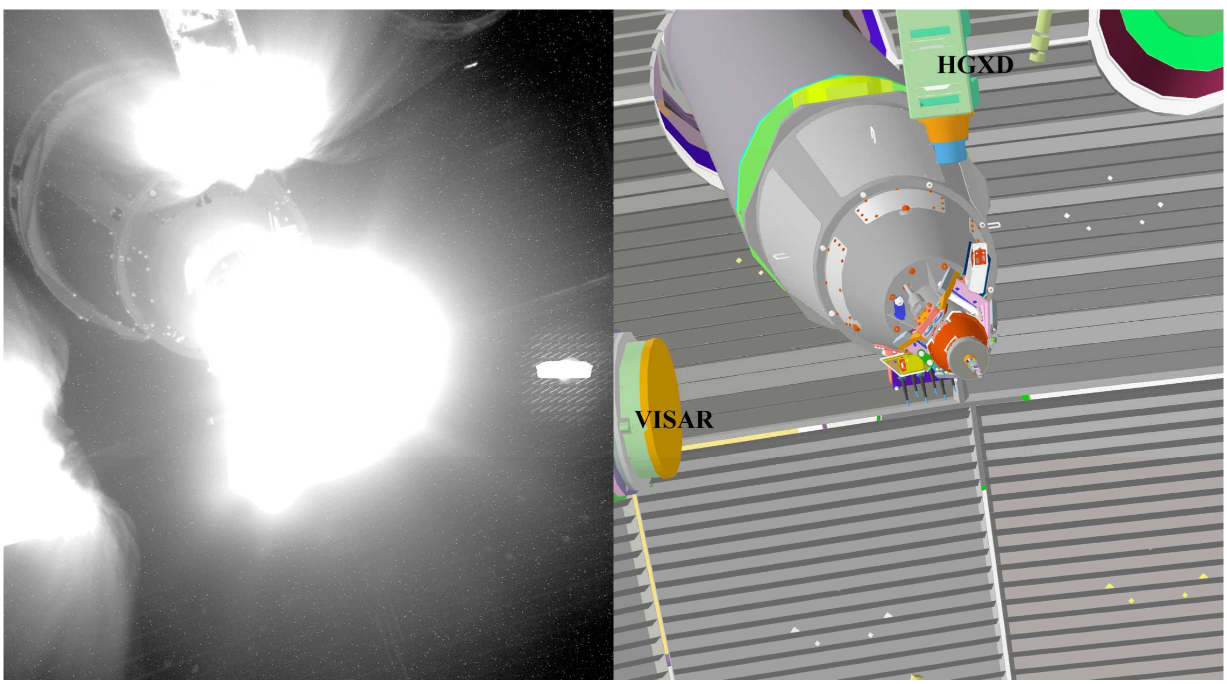

Figure 4. NIF Shot N140719 H_Cval_Altabl_pinr July 19, 2014

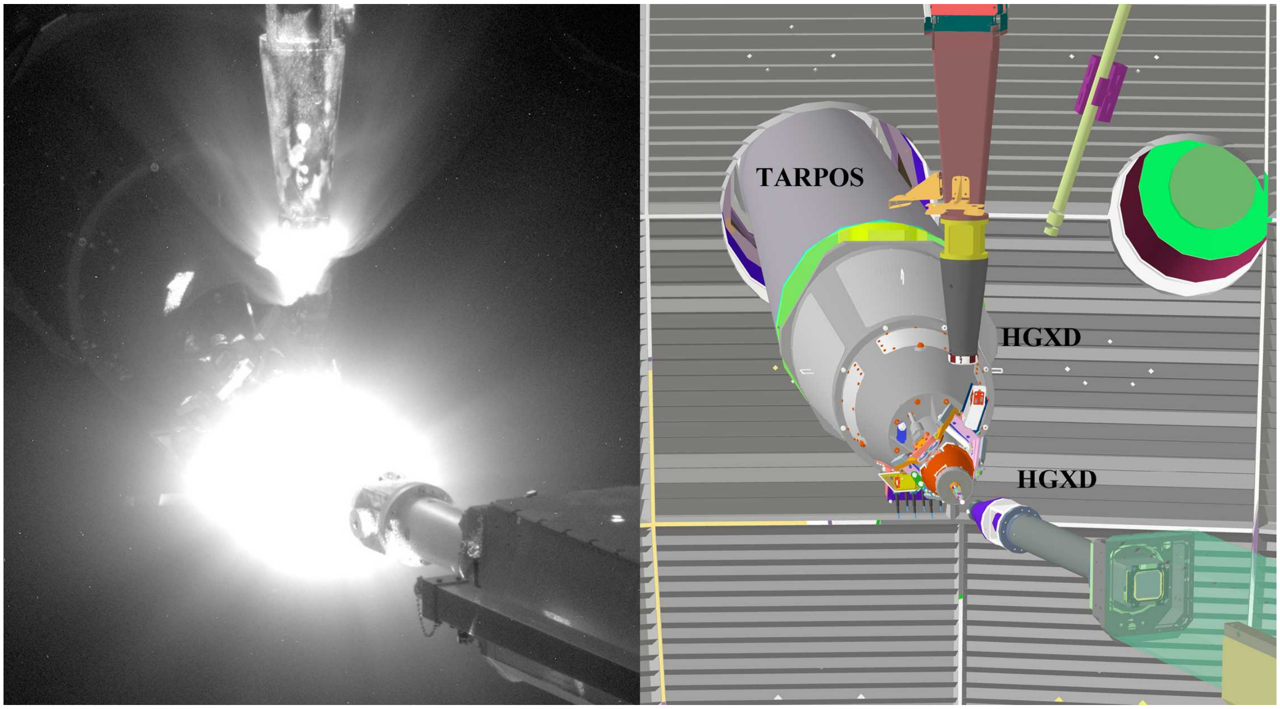

Figure 5. NIF shot N140811 I_Shap_2DConA_SSw_So4a, August 11, 2014

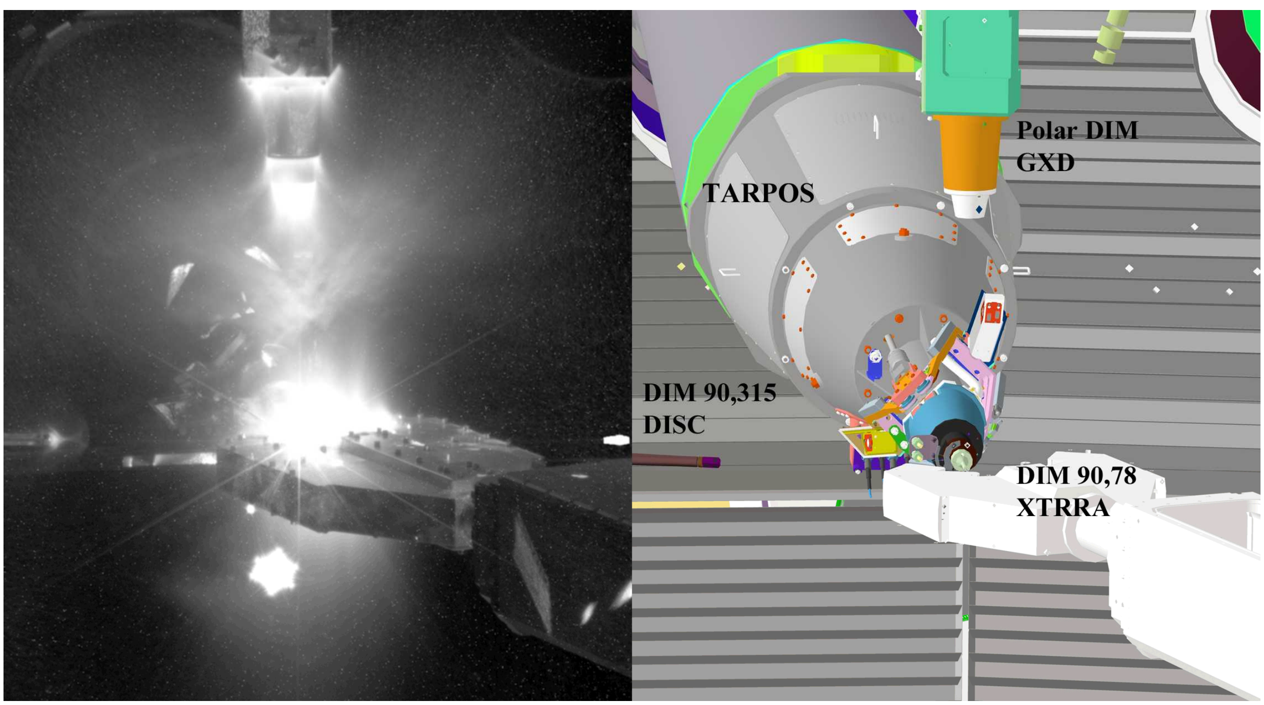

Figure 6. NIF shot N150614 N_DoD_Xray_PDI_S02, June 14, 2015

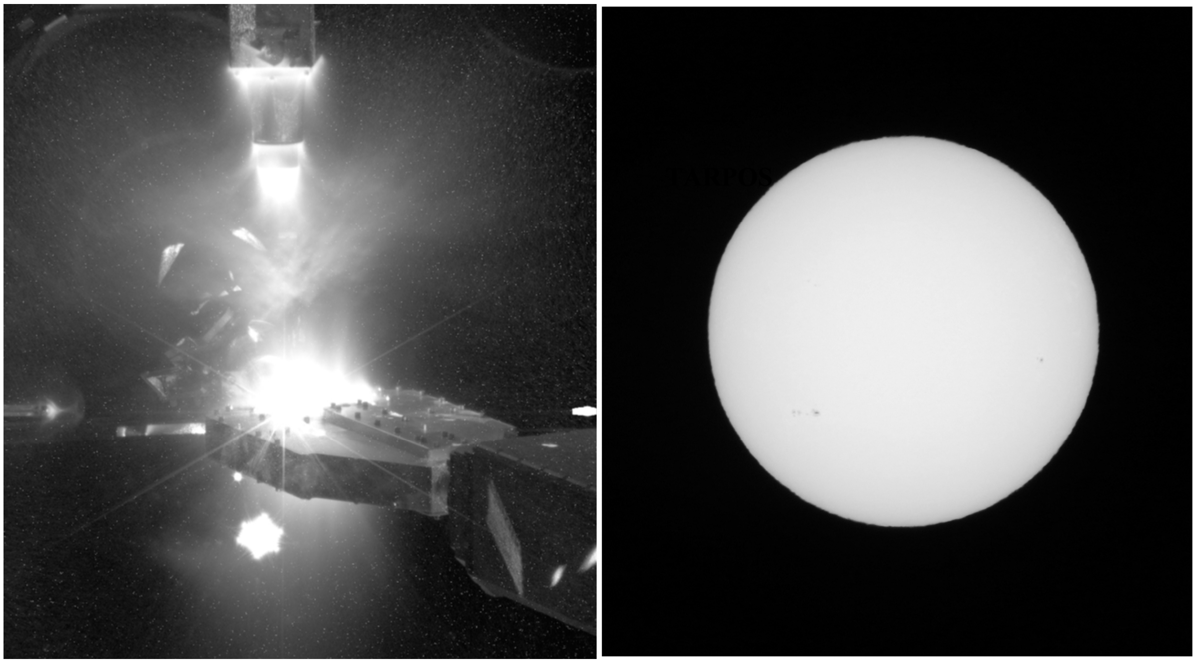

Figure 7. A million times brighter than the sun. For equivalent ISO and ND filtering, the exposure value (EV) is given by[1]: EV = $\log_2((f\#)^2/\text{shutter})$. Left: NIF shot N150614 - ISO 200, f/5.6, ND5.5, effective shutter 3 nanoseconds., equivalent to 50 EV. Right: Solar Photo w/ sun spots - ISO 200, f/22, ND2.5, shutter 125 microseconds, equivalent to 30 EV. Incredibly, this represents a difference of 20 EV, or 20 stops, 2^{20} !

4. FUTURE WORK

Future work will fully integrate shot photography into the NIF shot cycle. We will reserve a dedicated target chamber port. Optical upgrades will enable:

- Use of a film camera for improved dynamic range
- Automated filter handling
- Filters for sampling visible SBS and SRS light resulting from laser-plasma interactions
- Improved resolution. Longer focal lengths and with modern digital SLRs will provide vastly improved resolution. The present system resolves 0.6mm. We have proposed a system consisting of a 600 mm f/4 telephoto lens with a 2X teleconverter. With a modern digital body this setup is capable of resolving 30 microns.

5. ACKNOWLEDGEMENTS

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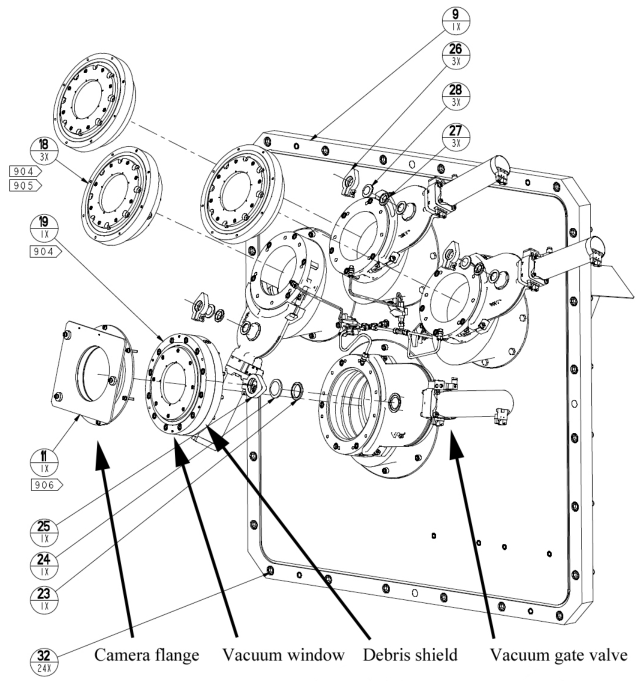

Figure 8. Shot time photography interface to the NIF target chamber

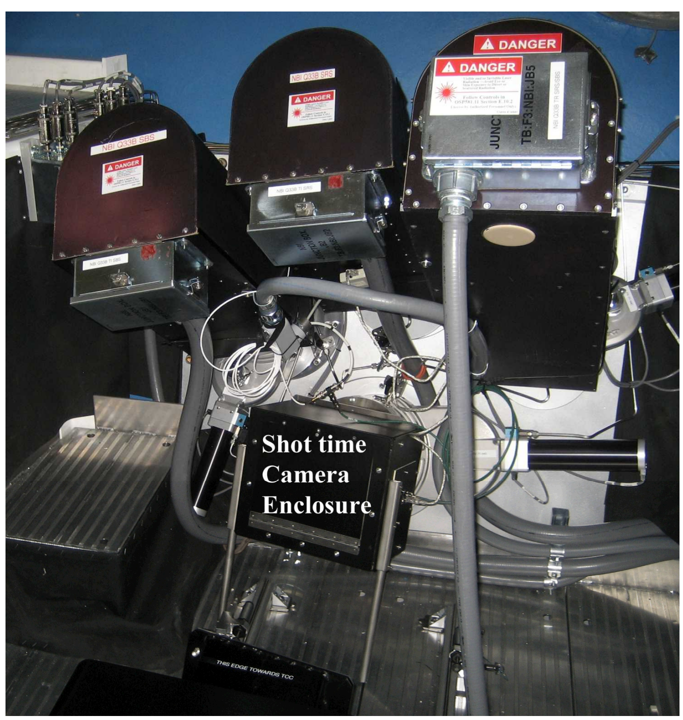

Figure 9. Shot time photography enclosure at the NIF target chamber

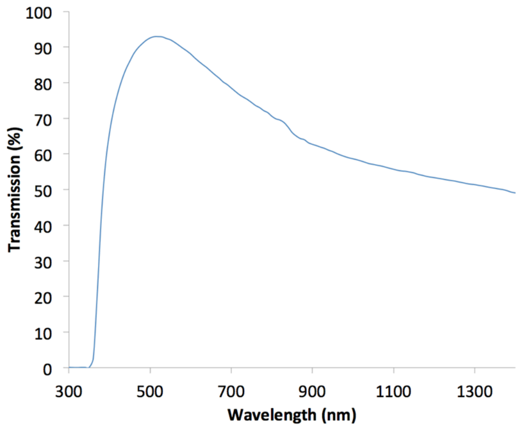

Figure 10. Lens transmission

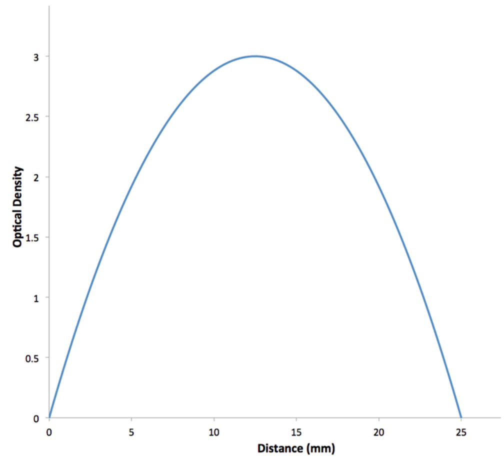

Figure 11. Apodizer

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[1] Ray, Sidney F. 2000. Camera Exposure Determination. In The Manual of Photography: Photographic and Digital Imaging, 9th ed. Ed. Ralph E. Jacobson, Sidney F. Ray, Geoffrey G. Atteridge, and Norman R. Axford. Oxford: Focal Press. ISBN 0-240-51574-9